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SECOND ANNUAL STATUS REPORT

(July 1, 1981 - June 30, 1982)

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Grant Title: Turbulence and Wave Particle Interactions in Solar-Terrestrial Plasmas

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This annual report was prepared for the National Aeronautics and Space Administration by the principal and co-principal investigators under grant NAGW-91 to the University of Colorado. Additional information on the research carried out in this reporting year is provided in the semi-annual status report covering the time period July 1981 to December 1981.

CONTENTS

Turbulence and Wave-Particle Interactions in Solar-Terrestrial Plasmas

A. Convection Zone Turbulence Driven by Ionization

Our theoretical modelling of two-dimensional compressible convection in the Sun, led by J. Toomre, has shown that convective flows can extend over many pressure scale heights without the nonlinear motions becoming supersonic, and that compressional work arising from pressure fluctuations can be comparable to that by buoyancy forces. These results are contrary to what has been supposed in prevailing mixing-length models for solar convection, and they imply a much greater degree of organized flow extending over the full depth of the convection zone. During this second year of the STTP program, we have concentrated on modelling the nonlinear penetration of motions into the stable region below the convection zone. We find that these compressible flows are dominated by downward directed plumes in the unstable zone. Their strong penetration into the region of stable stratification below excites a broad spectrum of internal gravity waves (Mihalas and Toomre 1981, 1982) there, and these in turn feed back upon the convection in the unstable zone to produce a rich time dependence. Such nonlinear mixing of the stable region below the solar conection zone is likely to have a major impact on magnetic dynamo theories: it is now suggested that dynamo action must occur in the stable zone so that the magnetic buoyancy of field bundles would not elevate them too rapidly to the solar surface. Our explicit modelling of compressible penetrative convection has revealed that such nonlinear flows are sufficiently vigorous to serve as the energy source for the dynamo action in the stable region (Hurlburt, Toomre and Massaguer 1982; Massaguer, Latour, Toomre and Zahn 1982).

The downward penetration of convective plumes and the associated excitation of internal gravity waves in the stable region below the convection zone is of very considerable importance in also another context. Namely, observations of

the oscillations of the Sun show the presence of global modes with low frequencies (or periods of order several hours or longer) that must be internal gravity waves. These modes of oscillations are in addition to those centered on periods of about five minutes which are certainly acoustic modes trapped largely in the convection zone. Although stochastic excitation by the intense turbulence of the convection is the very likely driving mechanism for the acoustic modes, it has been unclear as to just how the internal gravity waves can be excited. The reason for this is that the solar gravity modes are propagating waves only in regions of stable stratification below the convection zone, and must be evanescent in the convection zone itself. Further, it is very difficult to put energy into a wave mode by trying to wiggle it in regions where the mode is evanescent, such as in the convection zone. Thus it has been rather a puzzle as to just how the excitation of the solar gravity modes is actually accomplished. We believe that our recent results on the coupling of penetrating plumes with internal gravity modes may provide much of the answer, for these compressible convective flows base sufficient energy to excite a broad band of gravity modes. The driving thus occurs below the convection zone where the stratification allows propagating gravity waves, and depends critically upon the nonlinear and compressible properties of convection that lead to strong downward penetration of motions in the form of concentrated plumes.

B. Particle and Wave Processes in Solar Flares

One part of our work this year in this area, led by G. A. Dulk, has led to the discovery of "a missing link" in flare theory. We (Melrose and Dulk 1982a) found that extremely intense radiation at decimetric wavelengths ($\approx$0.3 to $\approx$3 GHz) is likely to be generated by an electron-cyclotron maser. This radiation is likely to have profound effects in the flare (Melrose and Dulk 1982b): enhancing the precipitation of fast electrons from a magnetic loop and

thus leading to bright X-rays from the footpoints, heating the coronal plasma by gyroresonance absorption, and transferring energy from one magnetic loop to another, probably inducing further instabilities, and thus spreading the course of the flare. We consider this discovery to be a major advance, so we will alter the priorities of our work. During the next year we will investigate in detail some of the implications of this mechanism.

In order to probe the conditions in the flare plasma, we (Dulk and Marsh 1982) have developed approximations to the gyrosynchrotron formulae which are simple but accurate for the range of harmonic numbers ≈ 10 to ≈ 100, both for thermal and power law electron distributions. Using these formulae we have developed the first inhomogeneous models of a flare plasma, models which are capable of producing the kinds of hard X-ray and microwave spectra observed (Dulk and Dennis 1982). Our conclusion is that homogeneous models used until now are incorrect, and that a multithermal distribution is required, one in which the temperature in a small flare core is $\approx 10^9$ K and in the surrounding layers the temperature drops gradually to $\approx 10^8$ K.

E. G. Zweibel and D. A. Haber (1982) studied the effect of the magnetic mirror force on the flare accelerated ions which produce γ-ray emission in solar flares. They showed that the ions could be trapped in the corona, thus delaying the γ-ray radiation.

Another part of this work, led by D. F. Smith, has concentrated on studies of the kinetic theory of thermal hard X-ray and microwave sources. Because it was shown that heat conduction in these sources has a global rather than a local nature, the strategy for attacking the problem has changed somewhat. When a part of the corona is heated to a temperature $>10^8$ K, collisionless conduction

fronts form which partially control the amount of heat lost locally in a thin front of thickness ≈100 km. However, the amount of heat lost is also partially controlled globally by the distribution in the whole source since electrons with sufficient energy can surmount the potential barrier of the front (Smith and Brown 1980) and deposit their heat beyond the front. Thus the problem of energy deposition also becomes global. A similar situation occurs in the solar wind.

Because the boundary conditions at the front are determined by global conditions, which have only been treated one-dimensionally to date, it only makes sense to perform a one-dimensional kinetic treatment of the front itself. This treatment must be sufficiently general to allow large variations in boundary conditions. We are presently programming this kinetic treatment of the conduction front using a Vlasov equation with quasilinear collision term for the electrons, a wave equation for the ion-acoustic waves and an equation for the electric field in the front. The ions are taken to have a Maxwellian distribution since deviations from this distribution are small if the ion-acoustic instability is not near saturation which is expected for our parameters. During the last year, the main accomplishment was setting up this program which is now in the execution phase. The number of fast electrons and the resulting total radiation signature of a thermal source (Smith and Orwig 1982) can only be derived self-consistently upon completion of this program which is expected to occur in the coming year. More immediate accomplishments of the past year have been completion of an examination of SMM data to compare predictions of thermal models with the data. These results have been published (Smith and Orwig 1982). This study which involved working with raw HXIS and HXRBS data was also good grounding in what data is likely to be available in the near future for testing the theoretical results expected to be obtained from our main effort. This effort will be continued in the coming year for large loops.

We have completed a study of the radiation signature of thick target beams (Smith and Emslie 1982). Due to the energy-dependent Coulomb cross section, the distribution function of electrons which is initially a power law develops a beam after traversing a given column density of coronal plasma as little as 10^{17} cm^{-2}. This tendency to develop a beam is counteracted by quasilinear relaxation. In a steady state there is still a region of positive slope because of the collisions and a nonthermal level of plasma waves. These waves lead to a level of second harmonic radiation of about 4×10^{-19} Wm^{-2} Hz^{-1} at about 2 GHz for typical parameters which is slightly more than the maximum microwave flux ever observed at this frequency. We have taken into account free-free absorption, but have not put in any gyroresonance absorption. To be significant the required field would have to be about 110 G or more throughout the entire source of dimensions of several tens of thousands of kilometers. This seems unlikely especially since this field rises to 1100 G for $n = 10^{11}$ cm^{-3}. Since such high microwave fluxes are very rarely observed, these results cast serious doubt on the thick target model for hard X-ray bursts in its present form. Either our understanding of beam transport is inadequate or only another type of model such as the thermal model being analyzed in detail (see above) is possible. We are continuing our work to see how the hard X-ray signature of such thick target beams will be modified by the modified distribution function. Since the electrons which escape through the conduction front in thermal models form a beam, it will also be applicable to the analysis of those sources.

C. Types III and II Solar Radio Emission

Our research in this area, led by M. Goldman, has centered upon fundamental properties of the plasma turbulence which underlies Type III solar radio wave emission. This theoretical work has been bolstered by continuing spacecraft experiments which have shown conclusively that electron streams emanate from the

Sun during Type III bursts, and that these streams excite electron plasma waves by a "bump-on-tail" instability.

In past years we have demonstrated that the dominant nonlinear physical effect governing the plasma-wave turbulence is the ponderomotive force of the plasma waves on the density (Goldman, Weatherall and Nicholson 1981). In our studies of the resulting wave-wave interactions, we considered the solar wind to be a homogeneous plasma in thermal equilibrium.

During the last year, we incorporated into our model some recently discovered properties of the ambient solar wind which appear to have important new consequences for the entire picture of the turbulence and related emission. In particular, we have taken into account the measured nonthermal character of the background electron distribution function, and the frequent presence of background density fluctuations over a wide range of scale sizes, from a hundred meters to a hundred kilometers (Hafizi et al. 1982).

Combined numerical and analytic studies have led to the following scenario for the nonlinear evolution of the stream-excited electron plasma waves: in the absence of significant background density fluctuations, the waves grow until they are large enough to undergo an induced scatter down to a low wavenumber "condensate" of spectral energy. The condensate is modulationally unstable to energy flow to higher wavenumbers, where the waves are damped by those nonthermal background solar wind electrons with phase velocities lower than the stream velocity. Due to this nonthermal feature of the solar wind electron distribution, the spectrum cuts off abruptly at wavenumbers which are only a few times the wavenumber of the beam-resonant waves. Hence, the nonthermal feature

prevents the self-focusing, or "collapse" of electron plasma waves down to very small scale sizes.

Calculations based on this physics yield a steady state turbulence with intensity on the order of the largest spacecraft-measured intensities, and predict a scale size for electron plasma wave turbulence on the order of 10 km. Inclusion of background density fluctuations with scale size between 5 and 50 km leads to suppression of the electron plasma wave turbulence, when the fluctuations are greater than one ten-thousandth of the background density (Goldman 1982).

A new statistical theory, which we have developed for electron plasma wave evolution in the presence of a near-gaussian distribution of background density fluctuations, tends to confirm our numerical results (Goldman and Dubois 1982). Included in this theory are the physical effects of absorption, emission, scattering and diffusion of the wave spectrum. We have solved the statistical equation in one-dimension to determine the effects of background density fluctuations of scale size of the same order as the beam-unstable plasma waves. Repeated large-angle backscatter has been found to occur in this case. For $\delta n/n$ on the order 10^{-3} - 10^{-4}, the instability can be saturated, particularly in the presence of the expected non-thermal Landau damping by high energy electrons in the solar wind. This work is currently being prepared for publication (with postdoctoral research assistant, Dr. David Russell).

We have also explored the basis for any statistical theory of the dynamical (Zakharov) equations of the beam-driven plasma turbulence, by studying instrinsically chaotic behavior of the solutions to the dynamical equations as a function of the beam growth rate. These studies were performed under assumed

conditions of adiabatic ions, and with a truncation to a few Fourier modes. With three coupled modes, strange attractors and limit cycles were observed in phase space. With more modes included, limit cycles and chaos and intermittency were also observed, as well as the development of fast (nonadiabatic) time-scale behavior. It is likely that a statistical treatment of the electron plasma-wave turbulence is only possible in regimes that show chaos. Finally, we note that the very intermittent behavior found theoretically is characteristic of spacecraft-measured wave intensities.

D. Plasma and MHD Effects of Coronal Transients and Coronal Evolution

One aspect of this study is a theoretical interpretation (by D. Gary working with G. Dulk and E. G. Zweibel) of collisionless shock waves in the corona, their acceleration of electrons to produce Langmuir waves and the subsequent conversion into radio waves. We have a set of observations of type II (shock wave) radio bursts in conjunction with visible light observations (from SMM) of a coronal transient and a unique "shell" of Thomson-scattered light. The latter has been shown to have an Alfvenic Mach number $M_A \approx 1.7$ and thus a shock must accompany it, yet no type II burst was observed in its vicinity (Gary et al. 1982). Instead the type II burst was observed to be at the side of slower, more massive ejected material--not even near the faster moving leading edge. Our suggestion to explain these unexpected results involves the shock angle, which must have been more favorable for producing nonthermal particles and waves at the side of the transient loop. Further investigation of this idea is underway.

E. Zweibel has continued work on equilibrium magnetic field structures and their stability. Three types of problems have been identified: finding new equilibria, studying instability using existing stability criteria, and

developing new criteria. In the first category there is now motivation to construct two-dimensional equilibria in which $P + \frac{B^2}{8\pi}$ is constant, since it has been shown that such equilibria are stable. In fact, we showed that the well known Kippenhahn and Schluter prominence model is stable by virtue of this criterion (Zweibel 1982). In the second category, future study will concentrate on stability of two families of equilibria: the loop structures rooted in a lower boundary found by Zweibel and Hundhausen (1982) and the plasma condensations found by Low, Zweibel and Hundhausen (1982). Finally, the stability analysis done so far applies to systems in which the magnetic fieldlines lie in parallel planes. It is extremely important to extend the analysis to three-dimensional, sheared fields, since fields occurring in nature are three-dimensional.

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Hurlburt, N. E., Toomre, J., and Massaguer, J. M. 1982 "Nonlinear penetrative convection in a compressible medium," to be submitted to Astrophys. J.

Low, B. C., Hundhausen, A. J., and Zweibel, E. G. 1982 "Nonlinear periodic solutions for the isothermal magnetostatic atmosphere," to be submitted to Phys. Fluids.

Massaguer, J. M., Latour, J., Toomre, J., and Zahn, J.-P. 1982 "Penetrative cellular convection in a stratified atmosphere," to be submitted to Astron. Astrophys.

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Zweibel, E. G. 1982 "A sufficient condition for the stability of atmospheres with magnetic fields," Astrophys. J., 258, L53.

Zweibel, E. G., and Haber, D. A. 1983 "The propagation of energetic ions in magnetic loops and γ-ray emission from solar flares," Astrophys. J. (in press, January 15, 1983 issue).

Zweibel, E. G., and Hundhausen, A. J. 1982 "Magnetostatic atmospheres: a family of isothermal solutions," Sol. Phys., 76, 261.

Appendix A

Publications Related to this Grant
(inclusive; status as of Sept 1982)

1. "Stellar Convection Theory. III. Dynamical Coupling of the Two Convection Zones in A-Type Stars by Penetrative Motions," J. Latour, J. Toomre, and J.-P. Zahn, Astrophys. J. **248**, 1081 (1981).

2. "Internal Gravity Waves in the Solar Atmosphere. I. Adiabatic Waves in the Chromosphere," B. W. Mihalas and J. Toomre, Astrophys. J. **249**, 349 (1981).

3. "Solar Five-Minute Oscillations as Probes of Structure in the Subphotosphere," F. Hill, J. Toomre, and L. J. November, in Pulsations in Classical and Cataclysmic Variable Stars (ed. J. P. Cox and C. J. Hansen), pp. 139-146 (1982).

4. "Reviews of Time-Dependent Convection and Attempts to Couple it to Pulsation in Stars," J. Toomre, in Pulsations in Classical and Cataclysmic Variable Stars (ed. J. P. Cox and C. J. Hansen), pp. 170-181 (1982).

5. "Time-Dependent Solutions of Multi-Mode Convection Equations," J. Toomre, D. O. Gough, and E. A. Spiegel, J. Fluid Mech., in press (1982).

6. "Internal Gravity Waves in the Solar Atmosphere. II. Effects of Radiative Damping," B. W. Mihalas and J. Toomre, Astrophys. J., in press (1982).

7. "Nonlinear Modal Analysis of Penetrative Convection," J.-P. Zahn, J. Toomre, and J. Latour, Geophys. Astrophys. Fluid Dynam., in press (1982).

8. "Nonlinear Anelastic Modal Theory for Solar Convection," J. Latour, J. Toomre, and J.-P. Zahn, Sol. Phys., in press (1982).

9. "On the Detection of Subphotospheric Convective Velocities and Temperature Fluctuations," D. O. Gough and J. Toomre, Sol. Phys., in press (1982).

10. "Solar Five-Minute Oscillations as Probes of Structure in the Subphotosphere," F. Hill, J. Toomre, and L. J. November, Proc. Pulsating Star Conference, in press (1982).

11. "Variability in the Power Spectrum of Solar Five-Minute Oscillations," F. Hill, J. Toomre, and L. J. November, Sol. Phys., in press (1982).

12. "Single-Mode Theory of Diffusive Layers in Thermohaline Convection," D. O. Gough and J. Toomre, J. Fluid Mech., in press (1982).

13. "Penetrative Cellular Convection in a Stratified Atmosphere," J. M. Massaguer, J. Latour, J. Toomre, and J.-P. Zahn, to be submitted to Astron. Astrophys. (1982).

14. "Nonlinear Penetrative Convection in a Compressible Medium," N. Hurlburt, J. Toomre, and J. Massaguer, to be submitted to Astrophys. J. (1982).

15. "Two-Dimensional Compressible Convection Extending Over Multiple Scale Heights," N. Hurlburt, J. Toomre, J. M. Massaguer, and E. Graham, to be submitted to Astrophys. J. (1982).

16. "Radio Emission From AM-Herculis-type Binaries," G. Chanmugam and G. A. Dulk, Astrophys. J., Part 2, **255**, L107 (1982).

17. "Simplified Expressions for the Gyrosynchrotron Radiation from Mildly-relativistic, Nonthermal and Thermal Electrons," G. A. Dulk and K. A. Marsh, Astrophys. J., **259**, 350 (1982).

18. "Electron-Cyclotron Masers as the Source of Certain Solar and Stellar Radio Bursts," D. B. Melrose and G. A. Dulk, Astrophys. J., **259**, 844 (1982).

19. "Radio Wave Heating of the Corona and Electron Precipitation During Flares," D. B. Melrose and G. A. Dulk, Astrophys. J., Part 2, **259**, L41 (1982).

20. "Microwaves and Hard X-Rays from Solar Flares: Multithermal and Nonthermal Interpretations," G. A. Dulk and B. R. Dennis, Astrophys. J., **260**, 875 (1982).

21. "Terrestrial Kilometric Radiation: The Cyclotron Theory," D. B. Melrose, K. G. Rönnmark, and R. G. Hewitt, J. Geophys. Res., in press (1982).

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24. "Mechanism for Particle Acceleration and Radio Emission from AM Herculis," G. Chanmugam and G. A. Dulk, submitted to IAU Colloquium No. 72 (August 1982).

25. "Synchronization of AM Herculis-type Binaries," G. Chanmugam and G. A. Dulk, to be submitted to Astrophys. J. (1982).

26. "A Sufficient Condition for the Stability of Atmospheres with Magnetic Fields," E. G. Zweibel, Astrophys. J., **258**, L53 (1982).

27. "Confinement of Cosmic Rays in Molecular Clouds," E. G. Zweibel and J. M. Shull, Astrophys. J. **259**, 859 (1982).

28. "The Propagation of Energetic Ions in Magnetic Loops and γ-ray Emission from Solar Flares," E. G. Zweibel and D. Haber, Astrophys. J., in press (1982).

29. "Nonlinear, Periodic Solutions for the Isothermal Magnetostatic Atmosphere," B. C. Low, A. J. Hundhausen, and E. G. Zweibel, to be submitted to Phys. Fluids (1982).

30. "Comparison of Theoretically Predicted and Observed Solar Maximum Mission X-ray Spectra for the April 13 and May 9, 1980 Flares," D. F. Smith and L. E. Orwig., Astrophys. J. 258, 367 (1982).

31. "Microwave Signature of Solar Thick Target Electron Beams," D. F. Smith and A. G. Emslie, submitted to Astrophys. J. (1982).

32. "Solitons and Ionospheric Heating," J. C. Weatherall, J. Sheerin, D. Nicholson, G. Payne, and M. V. Goldman, J. Geophys. Res. A. 87, 823 (1981).

33. "Langmuir Collapse in a Weak Magnetic Field," M. V. Goldman, J. C. Weatherall, and D. R. Nicholson, Phys. Fluids 24, 688 (1981).

34. "Parametric Instabilities in a Weakly Magnetized Plasma," J. C. Weatherall, M. V. Goldman, and D. R. Nicholson, Astrophys. J. 246, 306 (1981).

35. "Nonlinear Evolution Equations, Recurrence, and Stochasticity," B. Hafizi, Phys. Fluids 24, 1791 (1981).

36. "Chaotic (Strange) and Periodic Behavior in Instability Saturation by the Oscillating Two-Stream Instability," D. A. Russell and E. Ott, Phys. Fluids 24, 1976 (1981).

37. "Scattering and Collapse of Langmuir Waves Driven by a Weak Electron Beam," B. Hafizi, J. C. Weatherall, M. V. Goldman, and D. R. Nicholson, Phys. Fluids 25, 392 (1982).

38. "Wave-wave Interaction and the Self-focusing of Langmuir Waves," J. C. Weatherall, Phys. Fluids Res. Notes 25, 212 (1982).

39. "Beam-Plasma Instability in the Presence of Low Frequency Turbulence," M. V. Goldman and D. F. DuBois, Phys. Fluids, 25, 1062 (1982).

40. "Ion Trajectories in a Space Charge Wave on a Relativistic Electron Beam," D. A. Russell and E. Ott, Phys. Fluids, in press (1982).

41. "Progress and Problems in the Theory of Type III Solar Radio Emission," M. V. Goldman, submitted to Sol. Phys. (1981).

42. "Modulational Interaction of Nonlinear Waves and Recurrence," B. Hafizi, submitted to Phys. Fluids (1981).

43. "Modulational Interaction of Langmuir Waves in One Dimension," B. Hafizi, submitted to Phys. Fluids (1982).

44. "Steady State Turbulence with a Narrow Inertial Range," J. C. Weatherall, D. R. Nicholson, and M. V. Goldman, submitted to Phys. Fluids (1982).

45. "Solitons and Ionospheric Modification," J. P. Sheerin, J. C. Weatherall, D. R. Nicholson, G. L. Payne, M. V. Goldman, and P. J. Hansen, submitted to J. Atmos. Terr. Phys. (1982).

Appendix B

Invited Papers

1. "Soliton Collapse and Electromagnetic Emission," Martin V. Goldman (at the invitation of the Soviet Academy of Sciences), Workshop on Plasma Physics and Controlled Thermonuclear Fusion, Telavi, USSR; October 8, 1980.

2. "A Review of Solar Radio Wave Emission," Martin V. Goldman, Radiophysics Laboratory, Commonwealth Scientific and Industrial Research Organization, Epping, Australia; March 1981.

3. "Strange Attractors," Martin V. Goldman, University of Sydney, Australia; March 1981.

4. "Solitary Waves and Solar Radio Wave Emission," M. V. Goldman, invited colloquium, University of New South Wales, Sydney, Australia, March, 1981.

5. "Langmuir Turbulence," Martin V. Goldman, invited paper at Workshop on Stochasticity and Turbulence, Los Alamos Center for Nonlinear Studies; June 1981.

6. "Coherence and Chaos in Nonlinear Systems," David A. Russell, Workshop on Stochasticity and Turbulence, Los Alamos Center for Nonlinear Studies; June 1981.

7. "Variability in the Power Spectrum of Five-Minute Oscillations," J. Toomre (with F. Hill and L. November), IAU Colloquium No. 66, Problems of Solar and Stellar Pulsations, Crimea, USSR, Sept. 1981 (Solar Physics, in press).

8. "On the Detection of Subphotospheric Convective Velocities and Temperature Fluctuations," D. O. Gough and J. Toomre, IAU Colloquium No. 66, Problems of Solar and Stellar Pulsations, Crimea, USSR, Sept. 1981 (Solar Physics, in press).

9. "Anelastic Modal Convection," J. Toomre (with J. Latour and J.-P. Zahn), IAU Colloquium No. 66, Problems of Solar and Stellar Pulsations, Crimea, USSR, Sept. 1981 (Solar Physics, in press).

10. "Turbulence and Wave Particle Interactions in Solar Terrestrial Plasmas, G. A. Dulk, M. V. Goldman, D. F. Smith, and J. Toomre, American Geophysical Union, San Francisco, California, December 1981 (<u>EOS Transactions</u> 62 (45), 1015 (1981).

11. "Heating of the Corona by Radio Waves During Flares," G. A. Dulk, High Altitude Observatory, National Center for Atmospheric Research, Boulder, Colorado; April 1982.

12. "Precipitation of Solar Flare Electrons by Maser Radiation," G. A. Dulk, NASA/Goddard Space Flight Center; May 1982.

13. "Theory of Type III Solar Radio Wave Emission," Martin V. Goldman, Institute for Theoretical Physics, University of California at Santa Barbara, Goleta, California; March 1982.

14. "Status of Observations of Type III Solar Radio Wave Emission," Martin V. Goldman, Institute for Theoretical Physics, University of California at Santa Barbara, Goleta, California; March 1982.

15. "Emission of Electromagnetic Waves from Beam-Plasma Systems," Martin V. Goldman, University of California at Berkeley; April 1982.

16. "Compressible Convection in the Solar Convection Zone," Juri Toomre, Observatory of Pic du Midi, Toulouse, France; June 1982.

17. "Five-Minute Oscillations of the Sun and their Coupling to Convection," Juri Toomre, University of Barcelona, Spain; May 1982.

Appendix C

Contributed Papers with Published Abstracts Related to this Grant

1. "Harmonic Emission by Adiabatically Collapsing Langmuir Solitons," B. Hafizi and M. V. Goldman, Plasma Physics Divisional Meeting of the American Physical Society, San Diego, Nov. 1980 (Bull. Am. Phys. Soc. **25**, 914 [1980]).

2. "Langmuir Collapse in a Weak Magnetic Field," J. C. Weatherall, M. V. Goldman, and D. Nicholson, Plasma Physics Divisional Meeting of the American Physical Society, San Diego, Nov. 1980 (Bull. Am. Phys. Soc. **25**, 984 [1980]).

3. "Dimension of Strange Attractors," D. A. Russell, J. D. Hanson, and E. Ott, Plasma Physics Divisional Meeting of the American Physical Society, San Diego, Nov. 1980 (Bull. Am. Phys. Soc. **25**, 989 [1980]).

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13. "Cosmic Ray Confinement in Molecular Clouds," E. G. Zweibel and J. M. Shull, International School of Plasma Physics, Varenna, Italy, August 1981.

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26. "A Kinetic Theory Formulation of the Anomolous Heat Conduction Problem for Solar Coronal Loops," D. F. Smith and L. M. Muth, American Geophysical Union, San Francisco, California, December 1981 (EOS Transactions 62 (45), 1008 [1981]).

27. "Solar Five-Minute Oscillations as Probes of Velocity and Temperature Fields," F. Hill, J. Toomre, and L. J. November, Amer. Astron. Soc., Boulder, Colorado, January 1982 (Bull. Am. Astron. Soc. 13, 860 [1981]).

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31. "On the Effects of Electron-Cyclotron Masers During Flares," G. A. Dulk and D. B. Melrose, Fifth International Symposium on Solar-Terrestrial Physics, XXIV COSPAR, Ottawa, Canada, May 1982 (Adv. Space Res. [Oxford: Pergamon]).

32. "Comparison of Theoretically Predicted and Observed Solar Maximum Mission X-ray Spectra for the April 13 and May 9, 1980, Flares," D. F. Smith and L. E. Orwig, Fifth International Symposium on Solar-Terrestrial Physics, XXIV COSPAR, Ottawa, Canada, May 1982.

Appendix D

Conferences, Seminars and Other Grant-related Activities

Martin V. Goldman was organizer of an international workshop on plasma physics at the Aspen Center for Physics, Aspen, Colorado, June 1980, 1981, 1982.

Martin Goldman, Dean Smith, George Dulk and Ellen Zweibel were participants in the Aspen Center for Physics Workshop on Nonlinear Plasmas, June 1981.

Series of 10 seminars on plasma physics in the solar terrestrial context at the Department of Astro-Geophysics, University of Colorado, Boulder, August-September 1981.

Martin V. Goldman and D. Smith were selected to serve on a U.S. National Academy of Sciences Panel on the "Physics of the Sun." A joint paper on solar radio emission has been completed and will be published by the Academy. Ellen Zweibel completed a joint paper with M. Forman and R. Ramaty on particle acceleration in solar flares for the same volume, 1981.

Ellen Zweibel attended the International School of Plasma Physics program in Plasma Astrophysics in Varenna, Italy in August-September 1981. She also attended a workshop on Coronal Heating in Procchio, Italy, September-October 1981.

Acquisition of a VAX-11/750 computer system, funded partly ($60,000) by the present grant and partly ($84,000) by a Spacelab contract from MSFC to Professors J. Toomre and J. Hart, June 1981.

Martin Goldman, Visiting Scientist at the Institute for Theoretical Physics, University of California at Santa Barbara, January-June 1982.

Martin Goldman participated in the Aspen Center for Physics Workshop on Nonlinear Plasmas, June 1982.

Ellen Zweibel attended the Institute for Theoretical Physics, University of California at Santa Barbara, July 1982.

Juri Toomre attended the Workshop on Compressible and Nonlinear Convection in Bagneres de Bigorre, France, May 1982.

Appendix E

Personnel Supported by Grant NAGW-91
1 July 1981 through 30 June 1982

Name	Position	Time
G. A. Dulk	Principal Investigator	4 MM[1]
M. V. Goldman	Co-Principal Investigator	3 MM[1]
D. F. Smith	Co-Principal Investigator	5 MM
J. Toomre	Co-Principal Investigator	3 MM[1]
E. G. Zweibel	Assistant Professor	1.5 MM
D. O. Gough	Visiting Senior Scientist	1 MM[2,3]
J. Latour	Visiting Senior Scientist	2 MM[3,4]
J. A. Massaguer	Visiting Senior Scientist	2 MM[3,4]
D. B. Melrose	Visiting Senior Scientist	0.5 MM[3,5]
J.-P. Zahn	Visiting Senior Scientist	1 MM[4]
B. Hafizi	Research Associate	2.0 MM[2]
L. A. Muth	Research Associate	2.5 MM
D. A. Russell	Research Associate	1.5 MM[2]
J. C. Weatherall	Research Associate	6.5 MM
T. S. Bastian	Graduate Research Assistant	5.5 MM
E. E. De Luca	Graduate Research Assistant	4 MM[5]
D. E. Gary	Graduate Research Assistant	4 MM[5]
D. A. Haber	Graduate Research Assistant	4 MM[5]
F. Hill	Graduate Research Assistant	4 MM[5]
N. E. Hurlburt	Graduate Research Assistant	4 MM

[1] 2 MM salary paid by the University of Colorado
[2] Salary paid from other sources.
[3] STTP paid subsistence expenses.
[4] Salary paid from French or Spanish sources.
[5] Portion of salary paid from other sources.

Appendix F

Distribution

SUBJECT: Annual Status Report for
University of Colorado Grant No. 1-5331-48 (NASA Grant No. NAGW-91)
Turbulence and Wave Particle Interactions in Solar-Terrestrial Plasmas
(Grant Year ending 30 June 1982)

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